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RESEARCH MEMORANDUM

AN INVESTIGATION IN THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL OF THE SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{30}$-SCALE MODEL OF THE BELL X-2 AIRPLANE

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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AN INVESTIGATION IN THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL OF THE SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{30}$-SCALE MODEL OF THE BELL X-2 AIRPLANE

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SUMMARY

An investigation of the spin and recovery characteristics of a $\frac{1}{30}$-scale model of the Bell X-2 airplane has been conducted in the Langley 20-foot free-spinning tunnel. The effects of control settings upon the erect- and inverted-spin and recovery characteristics of the model were determined for the model at the design gross-weight loading condition. The effects of varying the loading, the stabilizer incidence, and of extending the leading-edge and trailing-edge wing flaps were also determined.

The results of the model tests indicated that, for the loadings possible, the airplane would not spin in an erect attitude. It was indicated, however, that inverted spins might be obtainable from which recovery might be difficult unless the stick is moved laterally in the direction opposing that in which the pilot is turning.

INTRODUCTION

An investigation has been conducted in the Langley 20-foot free-spinning tunnel to determine the spin and recovery characteristics of a $\frac{1}{30}$-scale model of the Bell X-2 airplane. The airplane is a single-place, rocket-propelled, supersonic research airplane.

The erect- and inverted-spin and recovery characteristics of the model were determined at the design gross-weight loading. The effects of varying the loading, the stabilizer incidence, and of extending the leading-edge and trailing-edge wing flaps were also determined.

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SYMBOLS

b	wing span, feet
S	wing area, square feet
$\bar{c}$	mean aerodynamic chord, inches
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and fuselage reference line to mean aerodynamic chord (positive when center of gravity is below fuselage reference line)
m	mass of airplane, slugs
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-feet^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
ρ	air density, slugs per cubic foot
μ	relative density of airplane $\left(\frac{m}{\rho Sb}\right)$ [illegible] 9-14-49
α	angle between fuselage reference line and vertical (approx. equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	angle between span axis and horizontal, degrees
V	full-scale true rate of descent, feet per second
Ω	full-scale angular velocity about spin axis, revolutions per second

APPARATUS AND METHODS

Model

The $\frac{1}{30}$-scale model of the X-2 airplane was built by the Bell Aircraft Corporation, and was checked for dimensional accuracy and prepared for testing at the Langley Laboratory. A three-view drawing of the model is shown in figure 1 and a photograph of the model is presented in figure 2. Dimensional characteristics of the airplane represented by the model are given in table I. The values in table I for unshielded rudder volume coefficient, tail-damping ratio, and tail-damping power factor were computed by the method of reference 1; the value of the side-area moment factor was computed by the method of reference 2.

Most of the tests were conducted with the model ballasted with lead weights to obtain dynamic similarity to the airplane at an altitude of 15,000 feet ($\rho = 0.001496$ slug/cu ft). A few tests were also conducted with the model ballasted to represent the airplane at an altitude of 35,000 feet ($\rho = 0.00736$ slug/cu ft). The weight, moments of inertia, and center-of-gravity location of the airplane were obtained from data furnished by the Bell Aircraft Corporation. A remote-control mechanism was installed in the model to actuate the rudder for recovery attempts. Sufficient hinge moment was applied to the rudder during the recovery tests to move it fully and rapidly to the desired position.

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that described in reference 3 for the Langley 15-foot free-spinning tunnel, except that models are now launched by hand with spinning rotation into the vertically rising air stream, rather than being launched by spindle. The airspeed is adjusted until the drag of the model balances the weight and normally, after a number of turns in the established spin, recovery is attempted by moving one or more controls by means of a remote-control mechanism. After recovery, the model dives into a safety net. The model is retrieved, the controls reset, and the model is then ready for the next spin.

The spin data presented herein were obtained and converted to corresponding full-scale values by methods described in reference 3. The turns for recovery were measured from the time the controls were moved to the time the spin rotation ceased and the model dived into the net. For recovery attempts in which the model struck the safety net while it was still in a spin, the recovery was recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net, as >3. A >3-turn recovery, however, does not necessarily indicate an improvement over a >8-turn recovery. For recovery attempts in which the model did not recover in less than 10 turns, the recovery was recorded as ∞. When the model, after being launched with forced rotation into a spin, stopped rotating without movement of controls, the result was recorded as a "no-spin" condition.

In accordance with standard free-spinning-tunnel test procedure, tests were made to determine the spin and recovery characteristics of the model at the normal spinning-control configuration (elevator full up, ailerons neutral, and rudder full with the spin) and at various other aileron-elevator control combinations including zero and maximum settings of the surfaces for various model configurations. When spins were obtained, recovery was generally attempted by rapid full rudder reversal. As is customary, tests were also performed to evaluate the possible adverse effects on recovery of small deviations from the normal control configuration for spinning. For these tests, the elevator position corresponded to stick two-thirds of full back for erect-spin tests and two-thirds of full forward for inverted spins, and the ailerons were set at one-third of full deflection in the direction conducive to slower recoveries. Recovery was attempted by rapidly reversing the rudder from full with to only two-thirds against the spin. This particular control configuration and manipulation is referred to as the "criterion spin." Recovery characteristics of the model are considered satisfactory if recovery from this criterion spin requires $2\frac{1}{4}$ turns or less; this value has been selected on the basis of full-scale-airplane spin-recovery data that are available for comparison with corresponding model test results.

PRECISION

The model test results presented herein are believed to be the true values given by the model within the following limits:

α, degrees . . . . ±1
ϕ, degrees . . . . ±1
V, percent . . . . ±5
Ω, percent . . . . ±2
Turns for recovery:
From motion-picture records . . . . $\pm\frac{1}{4}$

Because of the impracticability of ballasting the model exactly and because of inadvertent damage to the model during spin tests, the measured weight and mass distribution of the model varied somewhat from the true scaled-down values. The following table shows the range of weight and mass-distribution variations measured for the model:

Weight, percent	0 to 1 high
Center-of-gravity location, percent $\bar{c}$	0 to 1 rearward
Moments of inertia:	
I_X, percent	7 high to 2 low
I_Y, percent	4 high to 4 low
I_Z, percent	2 high to 4 low

The accuracy of measuring the weight and mass distribution of the model is believed to be within the following limits:

Weight, percent	±1
Center-of-gravity location, percent $\bar{c}$	±1
Moments of inertia, percent	±5

The controls were set with an accuracy of ±1°.

Test Conditions

The mass characteristics and inertia parameters for loadings possible on the Bell X-2 airplane and for the loadings tested on the model are listed in table II.

The normal maximum control deflections, measured in the plane perpendicular to the hinge line, were:

Rudder, degrees	30 left, 30 right
Elevator, degrees	15 up, 15 down
Ailerons, degrees	17 up, 17 down
Leading-edge flaps, degrees	15 down
Trailing-edge flaps, degrees	45 down

The intermediate control deflections used in these tests were:

Rudder two-thirds deflected, degrees	20
Elevator two-thirds up, degrees	10
Ailerons one-third deflected, degrees	$5\frac{2}{3}$ up, $5\frac{2}{3}$ down

For erect-spin tests with the model in the design gross-weight loading condition, the stabilizer incidence of the model was varied from its normal 0° incidence to a value of leading edge up 7° and to leading edge down 10°. For other loading conditions, the stabilizer incidence was maintained at 0°. For inverted spins, the model stabilizer incidence was set at the 7° leading-edge-up setting. A few brief tests were also made with the rudder set at 40° with the spin, 10° more than is normal for the airplane. For the entire investigation, the landing gear was retracted and the cockpit was closed.

RESULTS AND DISCUSSION

Erect-Spin Characteristics

Design gross-weight loading condition.- Erect spins could not be obtained with the model for any control setting possible on the airplane for any of the three stabilizer incidences. The motion of the model, after the initial launching rotation was expended and the model started to leave the enforced spinning attitude, generally appeared to be a function of the aileron position. When the ailerons were held against the spin, the model usually became extremely oscillatory in roll and yaw, sometimes rolling inverted and sometimes going into a dive. When the ailerons were set neutral or with the spin, the oscillations of the model were slight and the model dived out of the initially imparted spinning motion.

Brief tests were conducted with the stabilizer incidence varied from its normal 0° setting to leading edge 10° down and leading edge 7° up. With the stabilizer incidence set at leading edge 10° down, the spin characteristics of the model were similar to those obtained with the stabilizer set at 0° incidence. When the stabilizer incidence was set at leading edge 7° up, the model still did not spin in an erect attitude; however, there was a tendency to spin inverted and, in one case when the ailerons were neutral and the elevators down (stick forward), the model actually went into an inverted spin after the initial erect launching rotation was expended.

Gross-weight loading condition.- The spin characteristics of the model in the gross-weight loading condition (weight of the model increased from the design gross-weight loading - see table II) were similar to the results obtained for the design gross-weight loading condition with the exception that the model sometimes went into an inverted spin when the initial launching rotation was expended. For this loading, the inverted spins were obtained if the ailerons were at neutral or with the spin rotation.

Landing-weight loading condition.— The spin characteristics of the model in the landing-weight loading condition (weight of the model decreased and moments of inertia changed somewhat from the design gross-weight loading — see table II) were similar to the spin characteristics of the model in the design gross-weight loading condition.

Center-of-gravity movement and mass variation.— In an endeavor to determine whether the nonspinning tendencies of the model were critically dependent on loading or whether the model loading fell well within a range that would promote nonspinning tendencies, tests were conducted alternately with the center of gravity moved forward 5 percent, weight increased along the fuselage and retracted along the wings $\left(\frac{I_X - I_Y}{mb^2} = -591 \times 10^{-4}\right)$, and weight increased along the wings and retracted along the fuselage $\left(\frac{I_X - I_Y}{mb^2} = -296 \times 10^{-4}\right)$. (See table II for complete mass characteristics of the three loadings.) The spin characteristics of the model for each of these three loadings were similar to the results obtained for the design gross-weight loading condition in that erect spins still were not obtained. These results are considered to be an indication that the resistance of the model to spin erect was not critically dependent on changes in loading that might normally be made on the corresponding airplane.

Increase in test altitude.— When the equivalent test altitude of the model was increased from 15,000 feet to 35,000 feet for the design gross-weight loading condition, the model still would not spin in an erect attitude. The model sometimes went into an inverted spin after the initial launching rotation was expended, however, when the ailerons were set in the direction of the spin rotation.

Effect of leading-edge and trailing-edge flaps.— Because of indications that the Bell X-2 airplane might be released from a "mother ship" at a desired altitude with trailing-edge and leading-edge flaps deflected, brief tests were conducted at the design gross-weight loading, 0° stabilizer setting, at an equivalent test altitude of 35,000 feet with both sets of flaps extended in combination, and with the trailing-edge flaps extended alone. The spin characteristics of the model for both conditions were the same as had been obtained previously with the flaps retracted in that erect spins still were not obtained. Tests were also made with the leading-edge flaps alone deflected (design gross-weight loading at an equivalent test altitude of 15,000 ft, 0° stabilizer setting) and still indicated no spins.

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Inverted-Spin Characteristics

Because the model for the design gross-weight loading condition had gone into an inverted spin after being launched erect when the stabilizer incidence was set at leading edge 7° up, all inverted spins were tested with this stabilizer incidence at this loading condition. The equivalent altitude for the tests was 15,000 feet. The inverted-spin and recovery characteristics obtained are shown in chart 1. The angle of wing tilt in the chart is given as up or down relative to the ground.

Inverted spins were obtained when the ailerons were set neutral or set in the same direction as the spin rotation, that is, controls "together" (stick right when rotation was to the pilot's right). The spins obtained were flat (α ranged from 64° to 73°) and recoveries from these spins by reversal of the rudder alone were usually unsatisfactory. Inverted spins could not be obtained when the controls were "crossed" (stick left, right rudder pedal forward for rotation to pilot's right). It thus appears that if an inverted spin is inadvertently obtained, rapid lateral movement of the stick in the direction opposite to that in which the airplane is rotating, and reversal of the rudder will terminate the spinning rotation. For example, in the case of an inverted spin with rotation to the pilot's right, the stick should be moved laterally to the left and the left rudder pedal should be moved forward for termination of the spin. Upon completion of recovery, the rudder and ailerons should be neutralized in order to eliminate any possibility of entering a spin in the opposite direction.

Supplementary Tests

Effect of increased rudder deflection.- In order to determine what factors other than loading might lead to erect spins for the model, brief tests were made with the rudder deflection increased to 40° with the spin so as to obtain additional pro-spin moment. It was observed that a very oscillatory spin could sometimes be obtained with both the ailerons and elevator neutral. This test was conducted for the loading wherein weight was extended along the wings and retracted along the fuselage. (See table II.) It was felt that recovery from this spin by rudder reversal would be rapid.

Effect of dimensional modifications.- The nonspinning tendencies of the model in an erect attitude, it was felt, might be attributable to the high value of side-area moment factor in conjunction with the rather heavy concentration of weight along the fuselage of the design. (See reference 2.) Ventral and dorsal fins were added to the model to reduce the side-area moment factor, and tests were also made with the nose length decreased. These modifications had no appreciable effect on the characteristics, and erect spins still were not obtained with the model. It thus appears that the combinations of loadings and dimensional configurations tested during the present investigation were not conducive of obtaining erect spins. The fact that inverted spins were obtainable may be due to a difference in wing effects when the model was erect and when it was inverted.

CONCLUSIONS

Based on results of a spin investigation of a $\frac{1}{30}$-scale model of the Bell X-2 airplane, the following conclusions regarding the spin and recovery characteristics of the airplane at altitudes from 15,000 feet to 35,000 feet are made:

1. The airplane will not spin in an erect attitude for any control setting, stabilizer incidence, or loading likely on the airplane.

2. Inverted spins may be obtained with the airplane for some control settings, from which recovery may be difficult unless the stick is moved laterally in the direction opposite to that in which the pilot is rotating. In an inverted spin with rotation to the pilot's right, for example, the stick should be moved laterally to the left, and the left rudder pedal should be moved forward. The tendency to spin inverted will increase as the up-stabilizer incidence (relative to the pilot), the weight of the airplane, or the altitude is increased.

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2. Stone, Ralph W., Jr., and Klinar, Walter J.: The Influence of Very Heavy Fuselage Mass Loadings and Long Nose Lengths upon Oscillations in the Spin. NACA TN 1510, 1948.

3. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. NACA Rep. 557, 1936.

TABLE I.— FULL-SCALE DIMENSIONAL CHARACTERISTICS OF THE BELL X-2 AIRPLANE AS REPRESENTED BY THE $\frac{1}{30}$-SCALE MODEL

Fuselage length, ft	37.83
Wing:	
Span, ft	32.28
Area, sq ft	260.40
Section	Circular arc 10 percent (maximum thick 50 percent chord normal to wing reference line)
Root chord incidence, deg	3
Tip chord incidence, deg	3
Aspect ratio	4.02
Sweepback (at quarter-chord line), deg	40
Dihedral (in root chord plane), deg	3
Mean aerodynamic chord length, in.	100.55
Leading edge of mean aerodynamic chord rearward of leading edge of wing at airplane center line, in.	79.42
Ailerons:	
Chord (rearward of hinge line), percent of wing chord	20.00
Area (rearward of hinge line), percent of wing area	8.29
Span, percent of wing semispan	50.36
Horizontal tail surfaces:	
Total area, sq ft	43.70
Elevator area, sq ft	8.40
Distance from center of gravity to elevator hinge line at plane of symmetry for normal design gross-weight loading, ft	13.93
Vertical tail surfaces:	
Total area, sq ft	38.60
Rudder area, sq ft	5.80
Distance from center of gravity to rudder hinge line at base for normal design gross-weight loading, ft	13.88
Unshielded rudder volume coefficient	0.00334 .0032
Tail-damping ratio	0.0658 .1444
Tail-damping power factor	220×10^{-6} 142×10^{-6}
Side-area moment factor	0.828

[redacted]

[redacted]

I.D
4806

Values from Report No. 52-947-006 – dated April 20, 1950
[illegible] Bellanca [illegible]

	Weight	CG in % M.A.C	Ix slug ft²	Iy slug ft²	Iz	Ix Prin axis slug ft²	Iz Prin axis slug ft²	Bet. C.G. axis and Prin axis
1 Weight Empty	9586	26.2	4961	22,000	25660	4930	25566	2° 13′
2 Gross Weight	23681.5	23.4	5139	38488	42124	5126	42084	1° 6′
3 Design Gross Weight	16557	22.6	5059	30249	33937	5041	33886	1° 23′
4 Landing Wt.	9800.7	22.1	4975	23581	27229	4951	27,157	1° 53′

Calculated inertia parameters [illegible] and 2

	$\frac{A-B}{mb^2}$	$\frac{B-C}{mb^2}$	$\frac{C-A}{mb^2}$
1	-549×10^{-4}	-118×10^{-4}	667×10^{-4}
2	-435	-47	483
3	-471	-68	539
4	-587	-115	702

[redacted]

TABLE II.– MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADINGS POSSIBLE ON THE BELL X-2 AIRPLANE AND FOR THE LOADINGS TESTED ON THE $\frac{1}{30}$-SCALE MODEL

[Model values converted to corresponding full-scale values; moments of inertia are given about center of gravity]

Number	Loading	Weight (lb)	Test altitude (ft)	Airplane relative density		Center of gravity		Moments of inertia			Inertia parameters		
				Sea level	Test altitude	$x/\bar{c}$	$z/\bar{c}$	I_X slug-ft^2	I_Y slug-ft^2	I_Z slug-ft^2	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
						Airplane values							
1	Design gross weight	16,557		25.72		0.244	0.008	5471	29,245	33,150	-443×10^{-4}	-73×10^{-4}	516×10^{-4}
2	Gross weight	22,500		34.96		.245	.011	5536	36,537	40,440	−425	−54	479
3	Landing weight	8,662		13.46		.243	.023	5382	22,026	25,936	−593	−139	732
						Model values							
1	Design gross weight	16,592	15,000	25.72	40.89	0.249	0.01	5336	29,240	31,887	-445×10^{-4}	-50×10^{-4}	495×10^{-4}
2	Gross weight	22,472	15,000	34.92	55.50	.243	.02	5510	38,008	41,127	−446	−43	489
3	Landing weight	8,614	15,000	13.41	21.32	.244	.02	5270	22,271	25,478	−609	−115	724
4	Center of gravity moved forward	16,592	15,000	25.72	40.89	.190	0	5707	29,298	31,799	−440	−47	487
5	Weight increased along fuselage and retracted along wings	16,386	15,000	25.42	40.45	.245	.01	5532	36,910	39,396	−591	−48	639
6	Weight increased along the wings and retracted along fuselage	16,629	15,000	26.01	41.07	.246	.02	6645	22,704	25,394	−296	−50	346
7	Design gross weight	16,557	35,000	25.72	83.19	.243	0	5505	28,233	32,176	−424	−74	498

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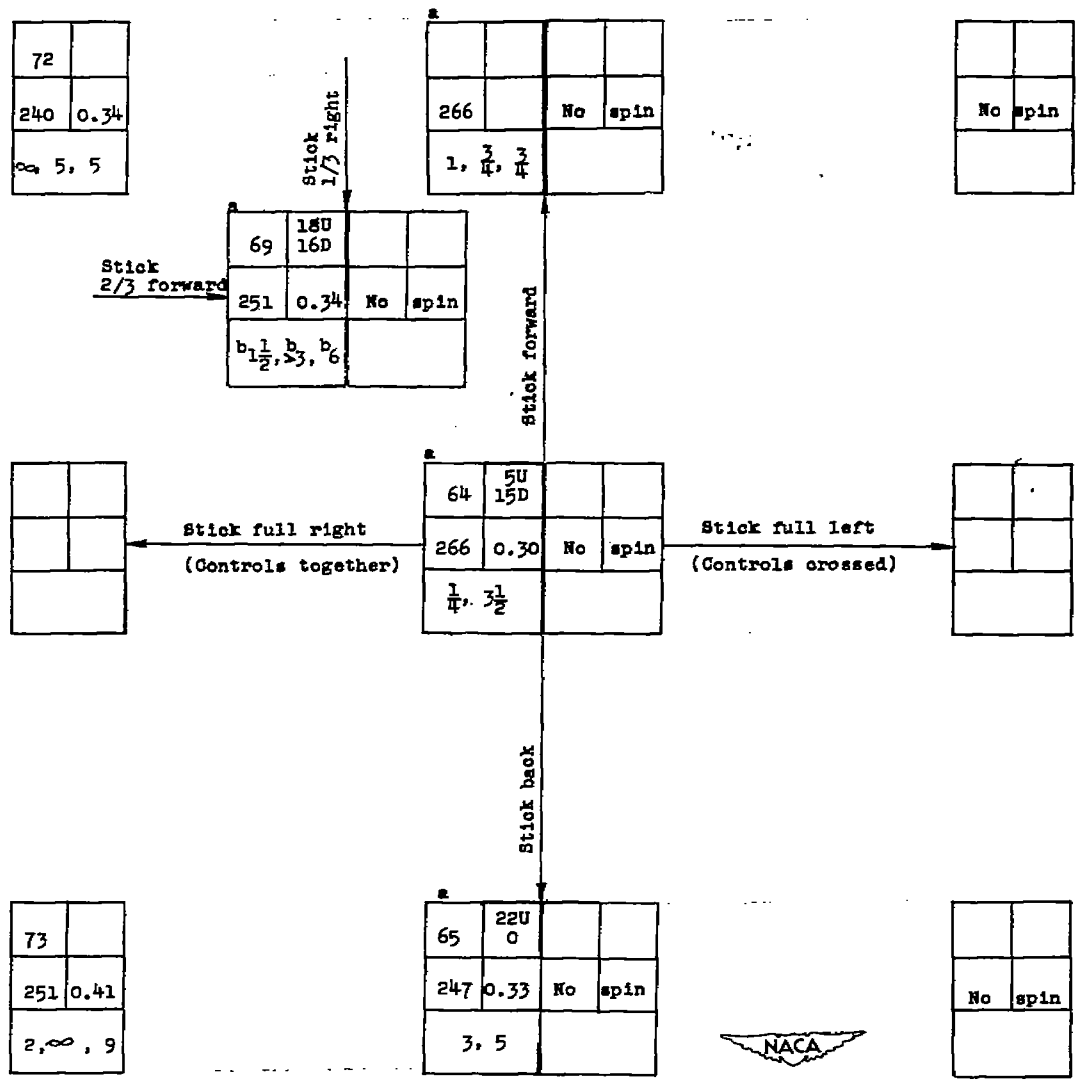
CHART 1.- INVERTED SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{30}$-SCALE MODEL OF THE BELL X-2 AIRPLANE; 7° LEADING-EDGE-UP STABILIZER SETTING

[Design gross weight loading; recovery attempted from, and steady-spin data presented for, tests with the rudder with the rotation to the pilot's right; recovery by full rapid rudder reversal unless otherwise indicated]



[a]Two conditions possible.
[b]Recovery attempted by reversing the rudder from full with to 2/3 against the spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

[redacted]

[redacted]

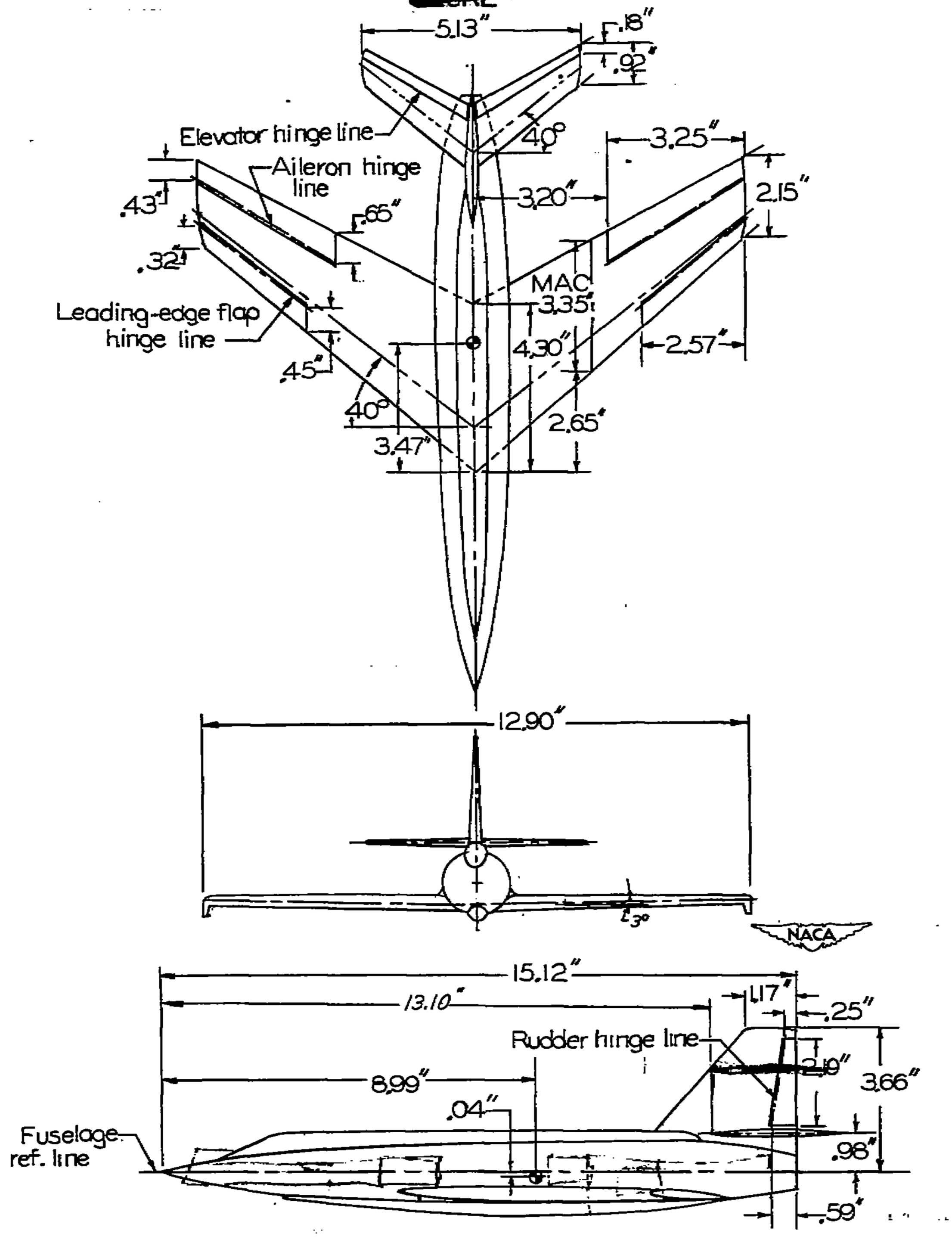


Figure 1.– Three–view drawing of the $\frac{1}{30}$–scale model of the Bell X–2 airplane as tested in the Langley 20–foot free–spinning tunnel. Center of gravity is shown at 24.4 percent of mean aerodynamic chord.

[redacted]

[redacted]

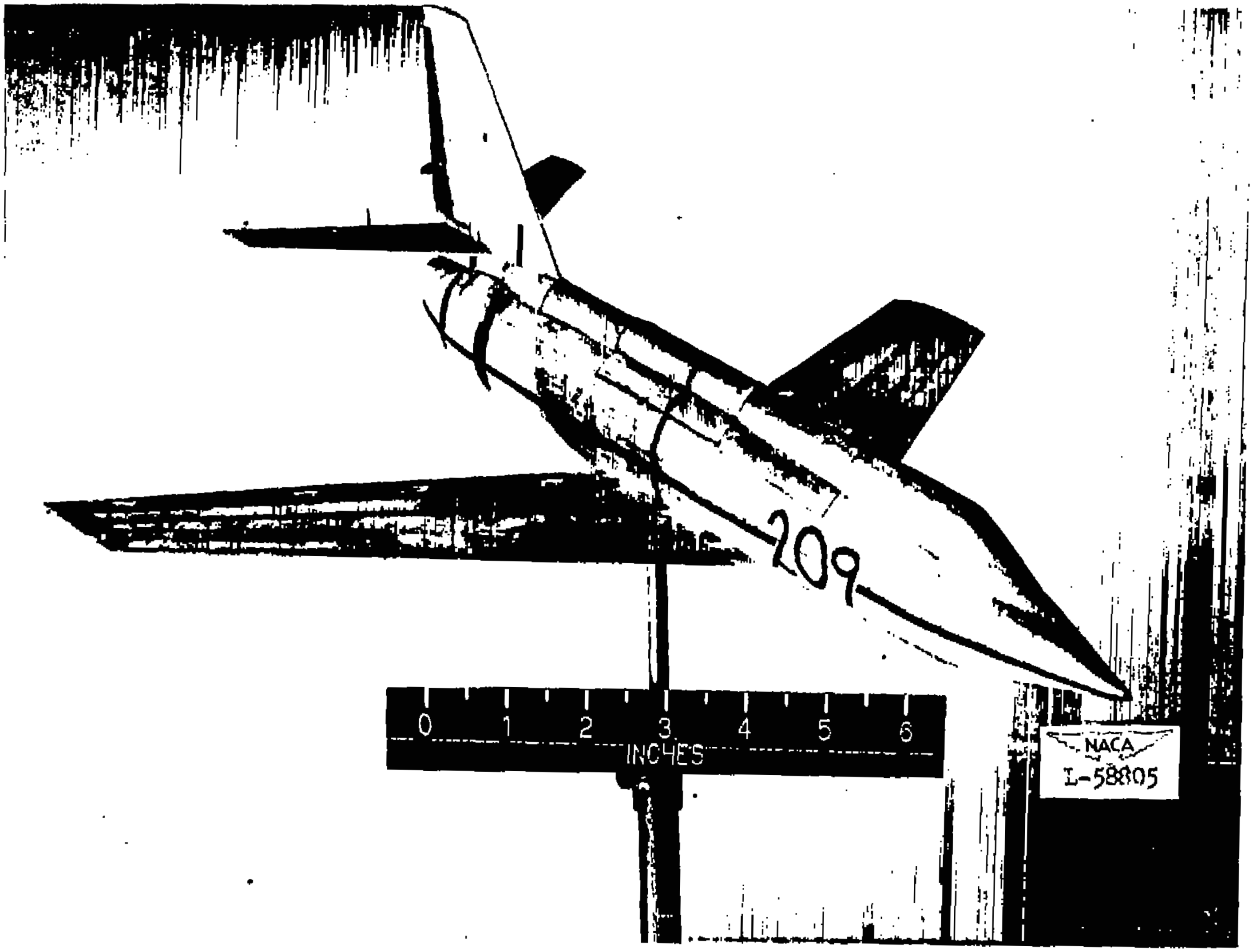


Figure 2.- Photograph of the $\frac{1}{30}$-scale model of the Bell X-2 airplane.

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ABSTRACT

An investigation of the spin and recovery characteristics of a $\frac{1}{30}$-scale model of the Bell X-2 airplane has been conducted in the Langley 20-foot free-spinning tunnel. The effects of control settings upon the erect- and inverted-spin and recovery characteristics of the model were determined for the model at the design gross-weight loading condition. The effects of varying the loading, the stabilizer incidence, and of extending the leading-edge and trailing-edge wing flaps were also determined.

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